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NATIONAL BUREAU OF STANDARDS REPORT

9527

FULL-SCALE RESIDENTIAL OCCUPANCY FIRE TESTS OF 1939

by

S. Rodak and S. H. Ingberg

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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ABSTRACT

Results are given for five full-scale fire tests in a simulated three-room residential occupancy building having gross fire loads within the range of 5.2 to 12 lb per sq ft. A similar furniture arrangement was used throughout the five fire tests, the load bring varied by the introduction of other combustibles such as paper, books, and foodstuffs. Air temperature measurements are reduced to form an "equivalent fire-duration" value in terms of the ASTM standard fire exposure curve.

1. Introduction

In 1939 a series of fire tests were performed in a one-story fire resistive building at the National Bureau of Standards to secure information on the intensity and the duration of fires that can arise in a residential occupancy building having different combustible loads. Similar furniture arrangements were used throughout the fire tests, the load being varied by the introduction of other combustibles. A summary of these test results had been previously reported [1]; however, there is at present a need for a more detailed report of the tests. These tests supplement earlier burn-out tests simulating office and record room occupancies[2].

2. Test Building

The test building, shown in Figures 1a to 1d, had walls of common red brick, and a roof and floor made of concrete. The interior walls were unfinished. In one test, a wood finish floor was laid over the concrete floor. The building, inside dimensions of 29 by 15 ft (Fig. 2) was fitted to represent a living room, dining room, and kitchen suite in four of the tests, and furniture storage in the fifth test. The amount of combustibles introduced was representative of the upper range in weights of combustible contents for residential occupancies at that time. The basic furniture arrangement is shown in Figure 3. Paper, books, foodstuffs, etc., were added to vary the fire loading of the five tests from 5.2 to 12 lb per square foot of floor area.

* The experiments reported were planned and conducted by Mr. Ingberg (retired). Mr. Rodak prepared the report.

In each test a portion of a loaded floor assembly (representing the floor above) was installed just below the ceiling and about 9 feet from the south living room wall. For example, in Test C, two nominal 2 by 10 inch, 16 ft-long wood joists were framed into the east and west brick walls. A floor section 32 inches wide was built up on these using 1-inch thick diagonal sub-flooring covered with tongue and groove finish flooring. This assembly was insulated above and on the side with asbestos and loaded with iron weights. The loading applied was not recorded but presumably was sufficient to stress the joists to working stresses common at the time of the tests. In Tests A, B and E, unprotected steel bar joists were placed across the living room while in Test D a 16-gauge (.062-inch thick) sheet-metal, multiple box-type cellular floor system was used. The joist arrangements used are tabulated in Table 1.

3. Test Methods

Spatial (air) temperature measurements were made at three levels by thermocouples inserted into the room through holes in the roof and through holes in the walls. The individual 18 B&S gage chromel-alumel wires passed through holes in porcelain insulators, which were protected by 1/2-inch standard iron pipes closed at the thermocouple bead end. As indicated in Figure 2 there were a total of 14 ceiling couples located one foot below the ceiling, seven couples located 6 ft 4 in. above the floor and six couples located 2 ft 6 in. above the floor.

Throughout the test, four pivoted concrete slab shutters in the windows, and dampers in the chimmey openings were varied to produce an "optimum" fire severity (See Appendix I, Test C). The initial ventilation openings were not always recorded (Tests A, B, E).

In each test, except for Test B, the fire was started at one point in the living room. The ignition of Test C was typical. Paper on the overstuffed sofa in the living room was ignited. After 40 seconds the sofa ignited. At 14 minutes, it was burning vigorously and the fire had spread to the piano and nearby tables. For Test B a total of five gallons of kerosene were poured over the furnishings in all three rooms. The three rooms were then ignited simultaneously.

4. Results of Test

A summary of the tests is displayed in Table II. Graphs of the time-temperature curves of the room are given in Figures 4-16. In each test, except for Test A, there are presented a total of nine time-

temperature curves: the average, the highest, and the lowest temperature, all rooms; the average, the high, and the low temperature, near the ceiling; and the average temperatures of the living room, dining room and kitchen. The average temperature, all rooms, was found by taking the average temperature value for the 27 thermocouples used in the test building at a given time. The highest (or lowest) temperature value at the given time of the 27 thermocouples was taken to be the highest (or lowest) temperature for all rooms. Similarly, the average temperatures for the dining room at a given time was taken to be the average temperature value of the eight dining room thermocouples at the time under consideration.

5. Discussion of Results

Ingberg [2] introduced the concept of an equivalent fire duration in order to correlate full-scale fire test information and to provide a means for answering questions such as: For a given fire loading in an enclosed space, what type of fire-resistive construction is required to confine a fire to that enclosure? He assumed that the area under the average spatial time-temperature curve for a fire in an enclosure, and an equal area under the ASTM E-119 standard time-temperature furnace heating curve (including the area under the resulting furnace cooling curve and above an arbitrary baseline) corresponded to the equivalent severity of exposure (see Figure 17). This method was used to find the equivalent fire duration values in Table II. Temperature cooling data after 1, 2, 4-and 8- hour heating periods following the standard time temperature curve have been taken for the furnace chambers at the National Bureau of Standards. Figure 18 presents graphs of the areas under the standard furnace heating curve plus the corresponding areas under the furnace cooling curves above the 150 °C base (or 300 °C base) versus time.

From Table II, we see that the equivalent fire duration (150°C base) for fires completely consuming the contents of the test building having a gross fire loading of 5.3 to 8.5 lb per sq ft is from 29 to 45 minutes. For a fire load of 12 lb/ft^2 representing furniture storage found in residential apartment buildings, the equivalent severity indicated is slightly less than an hour. These values are in substantial agreement with the reported data for the office and record room occupancy burn-out tests [2].

No correlation could be made between the limited fire duration data (time to reach maximum temperature) and the fire loading data.

Because of the local nature of the fire in Test A, the flames were extinquished after 145 minutes. The distribution of the combustible

load (5.2 lb/ft^2) with respect to the fire source limited the spread of flame in Test A. There was also some difficulty in the initial fire start of Test B (fire load, 5.3 lb/ft^2). After the first two minutes, the kerosene-fueled flames had died down. However, after eight minutes the individual fires in the rooms did build back up to cause flames to reach the ceiling.

For gross fire loads of 7.6 lb/ft^2 or less, the average spatial temperature within each room never exceeded the ASTM time-temperature curve. In Test D (8.5 lb/ft^2) and (12 lb/ft^2) the average spatial temperatures of the living room, dining room, and the ceiling temperatures did exceed the ASTM time-temperature curve for a period of 8 to 22 minutes.

Recent workers have shown that combustible loading is not the only significant factor influencing the magnitude of spatial temperatures for a fire in an enclosure. Theoretical investigations of Kawagoe and Sekine [3] indicate that the thermal characteristics of the enclosure can be important. In the present study no measurements were made which could be used to relate the heat flux density to the fire temperature in the enclosure. Other parameters influencing the enclosure temperatures are the rate of burning, the ventilation of the room and the size of the room.

The rate of burning in an enclosure with a single ventilation opening has been experimently verified [3] to be proportional to the ventilation factor $A\sqrt{h}$, where A is the area of the opening and h the height of the opening. Since a point is reached where a considerable amount of flaming will be outside the enclosure, it is not necessarily true that for the same fire loading a larger value of $A\sqrt{h}$ will allow for higher temperatures in the enclosure.

In a recent series of burn-out tests [4] conducted in a full-scale compartment (25' x 12' x 9.5' high), it was found that the time-temperature curves for comparable fire loads (up to 6 lb/ft^2) but different ventilation areas differ in an important manner. The time-temperature curve for a ventilation of ¼ of the wall area is always greater than that for the test having the same fire load but a ventilation of ½ the wall area. These temperature profiles are shown in Figure 19. (The wood crib tests with a loading of 6 lb/ft^2 and 12 lb/ft^2 continually had park temperatures higher than those defined for the ASTM Standard Time-temperature curve).

Thus, in the light of this recent work, it is not certain whether the 1939 tests did represent the realistic upper bound in fire severity for residential occupancies with typical furnishings.

5. Summary

Since more than one condition was varied for each test and only single experiments were made, no general conclusions were formed. The results of the burnout test for this test building and the furniture arrangement used may be summarized as follows:

1. The fuel load orientation with respect to the fire origin is important: in the test with a combustible load of 5.2 lb/ft^2, a fire originating in the living room did not spread to adjoining rooms.

2. Average spatial temperatures of individual rooms were generally lower than the ASTM standard time-temperature curve. However, for gross fire loads of 8.5 lb/ft^2 and 12 lb/ft^2 the average spatial temperatures of the living room, dining room, and the ceiling did exceed the ASTM time-temperature curve for periods up to 22 minutes.

The use of "equivalent fire duration" for a burnout test in an enclosure needs additional study. It may be that standard physical specimens as severity indicators will have to be devised and used to help relate the severity of burn-out tests to the ASTM standard fire exposure.

References

[1] "Evaluation of Fire-Resistance Requirements," Technical News Bulletin of the National Bureau of Standards, No. 274, February 1940, pp. 13, 14.

[2] S. H. Ingberg, "Tests of the Severity of Building Fires," Quarterly of the National Fire Protection Association, Vol. 22, No. 1, July 1928.

[3] K. Kawagoe and T. Sekine, "Estimation of Fire Temperature-Time Curve in Rooms," Japanese Ministry of Construction. Building Research Institute, BRI Occasional Report No. 11, Tokyo, April 1963.

[4] Butcher, Chitty, and Ashton, "The Temperatures Attained by Steel in Building Fires," Ministry of Technology and Fire Offices. Committee, Joint Fire Research Organization, Fire Research Technical Paper No. 15, London, May 1966.

Appendix I

Summary of Residential Occupancy
Fire Test Observations

Time (min.)

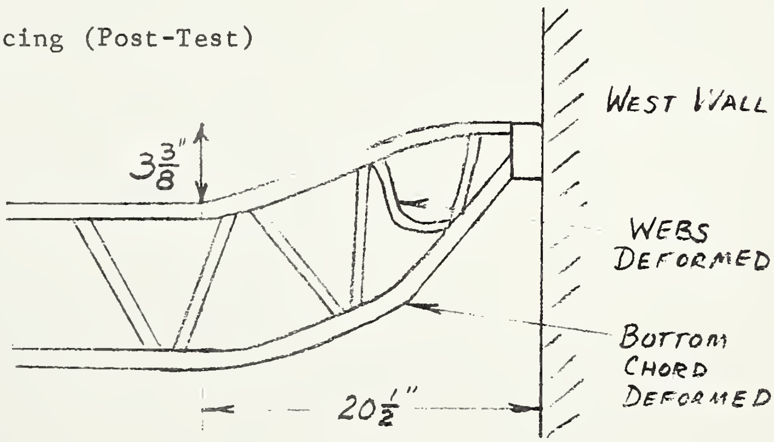
Test A

Time (min.)	
0	Fire load, 5.2 lb/ft^2. Room temperature 5 ^oC.
½	Paper burning on top of table to N of sofa.
5	Flaming in piano.
6½	S shutter open to 4".
11	Paper on table on N end of sofa flaming steadily. S side of piano flaming steadily.
18-23	S shutter opening varied from 4" to 9" to 14".
33	Table to S of sofa on fire.
44	S shutter open to 20½". Sofa about 2/3 consumed.
58	Flames up to joists (living room).
61	Fire over full width of piano.
63	Booktable and chair to N of piano on fire.
74	Joists of N group (24" spacing) buckled on west end.
100	Radio cabinet burning
145	Door opened to building. Water applied to remainder of piano frame and chair.

Post Test Observations

The sofa, south chair, end tables to south and north of piano, and the radio cabinet were completely consumed. Chair to east of radio cabinet only partly burned. Piano consumed except heavy frame members across top of back. Corner of rug charred under piano.

Bar-Joist, 24" spacing (Post-Test)

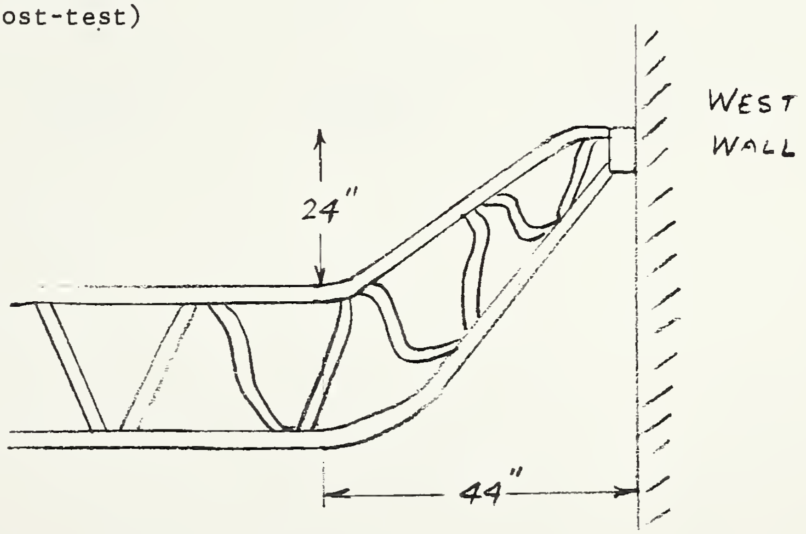


Time (min.)

Test B

0	Fire load, 5.5 lb/ft^2. Room temperature, 7 °C. Five gallons of kerosene distributed throughout living room, dining room and kitchen. Chimney closed. Rooms ignited simultaneously.
2	Dining room fires and kitchen fires out.
3	Corner shelves in dining room on fire, all other fires out. Chimney opened. N and S shutters open to 7".
4	E shelves (sideboard) in dining room burning.
4½	Piano burning.
5	W shutter open to 10".
8	Flames reaching joists on N side from piano.
14	N joist deflecting.
15½	West book shelf burst into flames.
20	S joists deflected approximately 14".
23	N shutter open to 6".
25	S side of kitchen on fire.
27	Dining room completely on fire.
28½	Joist on N side collapsed. Ties pulled out E and W side.
32	S shutter closed to 4", then to 2½".
50	Both of the book shelves and the piano burning. Dining room table and the sideboard in glowing pile. Shelves in pile of glowing debries in kitchen.
107	S shutter open to 2"; E shutter vertical; N shutter open to 3"; W open to 6".
250	Piano still flaming along length of wood on top -- coals glow at bottom, with some flame. Much less flaming from books in debris of W. bookcase.

South Bar Joist (Post-test)

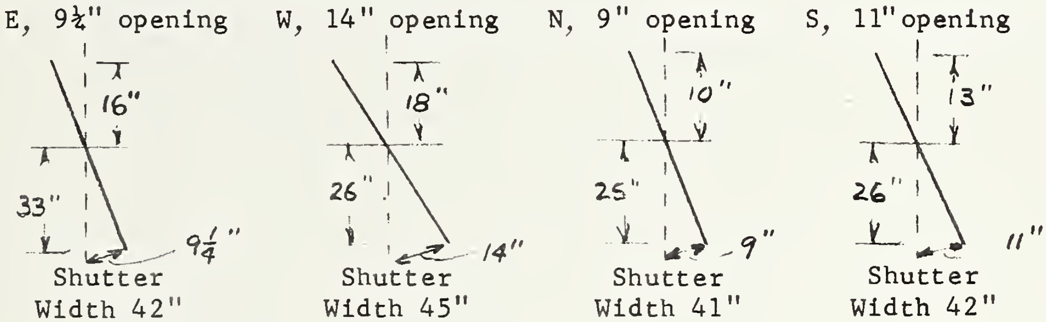


Time (min.)

Test C

0	Fire load, 7.9 lb/ft^2. Room temperature 23 °C. Door closed. Fire start by ignition of papers on N sofa area (living room). Shutters : E, 3½" open at bottom; (see diagram after 85 minutes); N, 4" open at bottom; W, 2" open at bottom; S open 3" at bottom.
0-5	Sofa ignited. Fire spread to piano and to floor covering near sofa. Door opened at 2 minutes.
15	W shutter open to 5½"; S & E open to 6".
42½	W end of wood joist ignited.
44	Sofa consumed. Piano burning vigorously; W half of joists and ceiling on fire.
46	Bookcase N of piano ignited.
51	Wood joist fell.
52	Vigorous flames from piano and the fallen wood joists. No general spread from floor covering (living room).
56	W shutter closed to 4".
57	Radio cabinet burst into flames.
60	W shutter opened to 11½".
72	Flashover in dining room.
79	Flashover in kitchen.
85	All combustibles reduced to flaming or glowing debris.

Post test shutter openings:



Time (min.)

Test D

0	Fire load, 8.5 lb/ft^2. Room temperature 10 $^\circ$C.
1½	N end of sofa in flames.
2½	Flames from piano reach steel floor joists.
12-35	All four shutter openings varied.
36-39	N and S floor joist section collapses (Steel angle did not give)
65	N shutter open to 13"; W open to 7"; S open to 11"; E open to 5".
210	Piano still burning under collapsed floor joist section. Glow in small debris in kitchen.

Time (min.)

Test E

0	Fire load, 12 lb/ft^2. Room temperature 4 $^\circ$C. N, W, & E shutters vertical. Chimney open. Fire start by ignition of shredded paper and exclesior in paper boxes located in S end (living room) of building. (The joist arrangement was apparently similiar to Tests A and B).
5-9	Flames reaching to ceiling and extending to center of living room.
18-21	Wood and furniture on N (Dining room) smoking from thermal radiation.
28	N shutter opening varied.
40	Building combustibles 3/4 consumed.
81	N shutter open to 16"; W shutter to 7"; S shutter to 12"; E shutter to 8".
180	Glow in debris.

Table I. Joist and Simulated Floor Arrangement Below Room Ceiling

	Test A	Test B	Test C	Test D	Test E
Description of Joists	Two pairs unprotected bar joists were placed to span the east and west living room walls, about 18" from ceiling. The north pair, framed into the east & west walls, was unanchored and had a 24" spacing. The south pair had a 16" spacing.	The same joist arrangement was used as in Test A	Two 2" x 10" x 16' long wood joists were framed into E & W walls, 16"-spacing. One inch nominal diagonal sub-flooring with standard T & G finish floor was used in 32" width. Both the edges and top of the flooring were insulated with heavy asbestos fabric.	The upper floor section consisted of 16gage steel metal multiple box-type assembled to be 6" thick, 4.6 ft wide. Rock wool was fitted along N&S edges. This assembly was supported at each end on 4" x 4" x ½" steel angles bolted to the walls. The E and W ends of the assembly were anchored by wire ties passing through walls. Two-inch gypsum slabs were placed on top and fastened to the floor units.	Joist arrangement apparently similar to Tests A & B
Load	North pair: Loaded to 35 lb/ft^2 of supported area (Stress: 8400 psi) South Pair: Loaded to 45 lb/ft^2 (10,800 psi) In each case, 2" gypsum blocks used to simulate the floor slab.	Load not recorded. Assumed same load was used as in Test A.	Load not recorded. Assumed to be sufficient to stress the joists to 1000 lb/in^2.	55 lb/ft^2 load, equal to ½ that recommended for the floor units used. (load in form of bricks placed on floor assembly).	
Remarks	At 74 min, north pair of joists buckled.	S joists deflected 14" at 20 min. N joist collapsed at 28 min	West end of joist ignited at 42½ min (Avg. ceiling temp 360 ^{o}C) Joist fell at 51 min.	At 36 min. S section sagged and N floor section collapsed; steel angle did not give.	

Table II. Residential Burn-out Tests of 1939

Test	Occupancy	Finish Floor	Fire 1/ Load lb/ft^2	Equivalent Fire Load 2/ lb/ft^2	Btu/ft^2 of floor Area	Equivalent Fire Duration 150 °C Base min	Equivalent Fire Duration 300 °C Base min	Time for Avg. All rooms to reach max. min	Remarks
A	Residential	Concrete	5.2	5.0 3/	40,190 3/	NOT TABULATED			Fire start by ignition of paper under N living room end table. Fire remained local to this section.
B	Residential	Concrete	5.3 (14% books)	5.3	45,000	29	20	35	Five gal. kerosene distributed through Liv. Rm., Din. Rm., Kit. Ignited rooms simultaneously
C	Residential	Concrete	7.9 (38% books)	7.6	61,000	33	22	75	Fire start by ignition of papers on sofa arm.
D	Residential	wood	8.5 (16% books)	8.4	67,000	45	34	40	Fire start by ingition of papers in NW living room section.
E	Furniture Storage	Concrete	12	12	96,000	54	52	35	Fire start by ignition of shredded paper and excelsior in paper boxes located in S end living room.

1/ Gross combustible weight divided by total floor area (427 ft^2).

2/ Gross heat value of combustibles divided by product of the heat value of 8000 Btu/lb and of the total floor area.

3/ Estimated from available data.

Fig. 1A - Residential Occupancy Test Building

Fig. 1B - Test Bldg, Interior   Test B (Pre-Test) Buckling of joists near wall support occurred in Test A.

Fig. 1C - Test Bldg. Interior   Test C (Pre-Test)

Fig. 1D - Test Bldg. Interior   Test C (Post-Test)

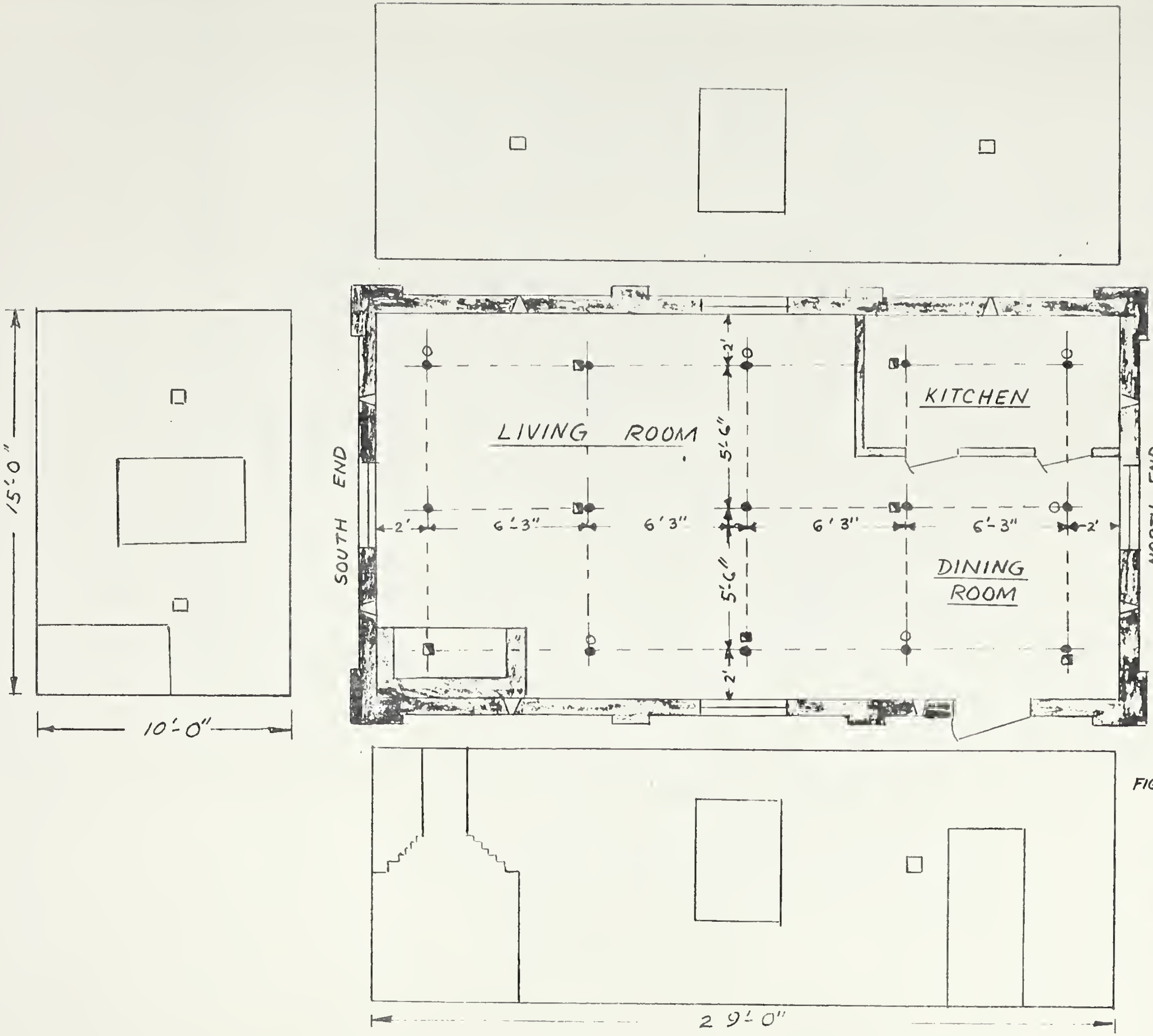


FIG. 2 - BUILDING PLAN AND THERMOCOUPLE PLACEMENT

NOTE: THERMOCOUPLES WERE INSERTED INTO ROOM THROUGH ROOF.
- ● CEILING COUPLES (14); 1 FT. BELOW CEILING
- ■ CENTER COUPLES (7); 6'-4" FROM FLOOR
- ○ LOWER COUPLES (6); 2'-6" FROM FLOOR

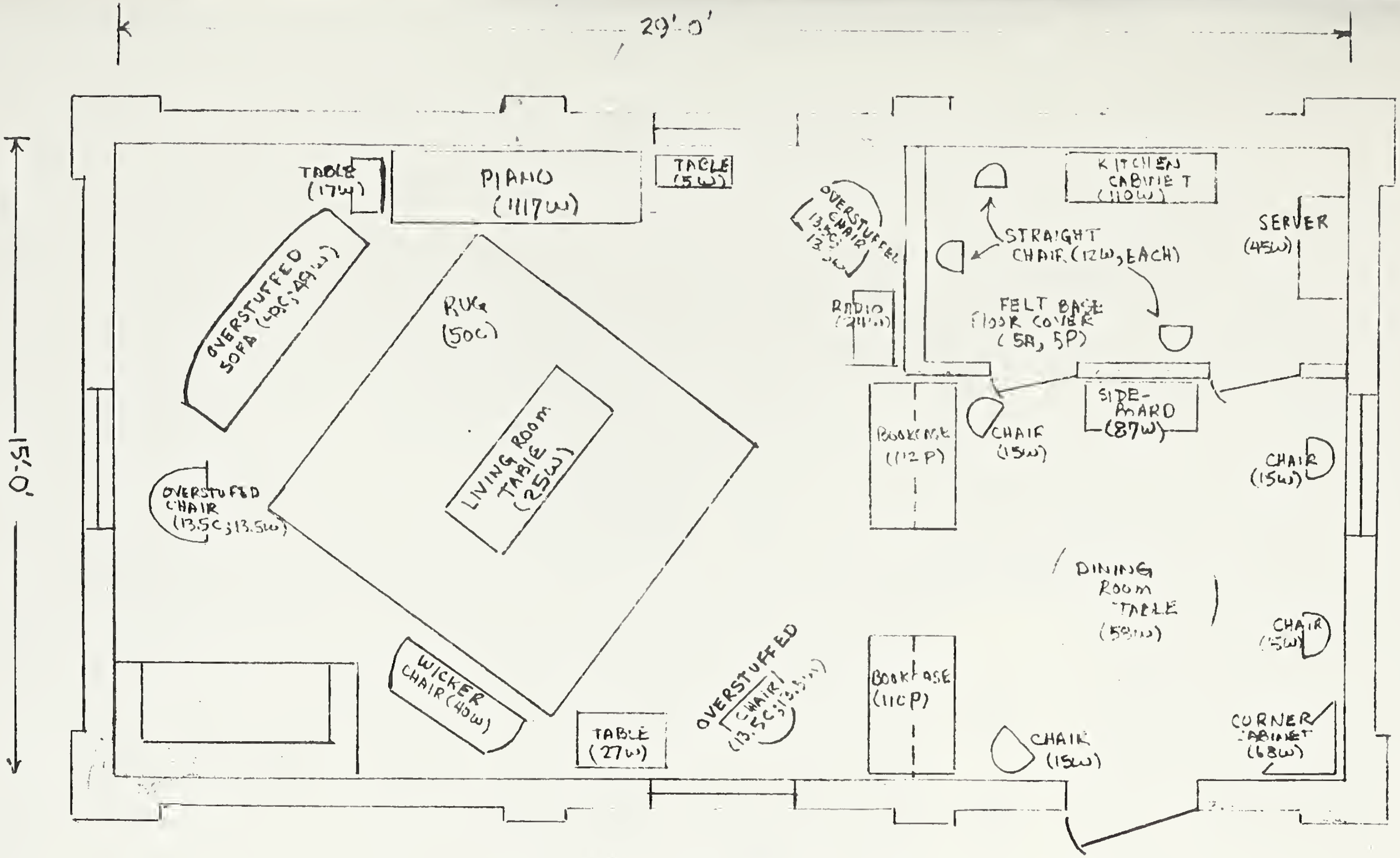


FIG. 3 — BASIC FURNITURE ARRANGEMENT

NOTE: NUMBER IN PARENTHESIS INDICATES WT. IN lb. of CLOTH (C), PAPER (P), WOOD (W), OR ASPHALT (A)

DRAWING NOT TO SCALE

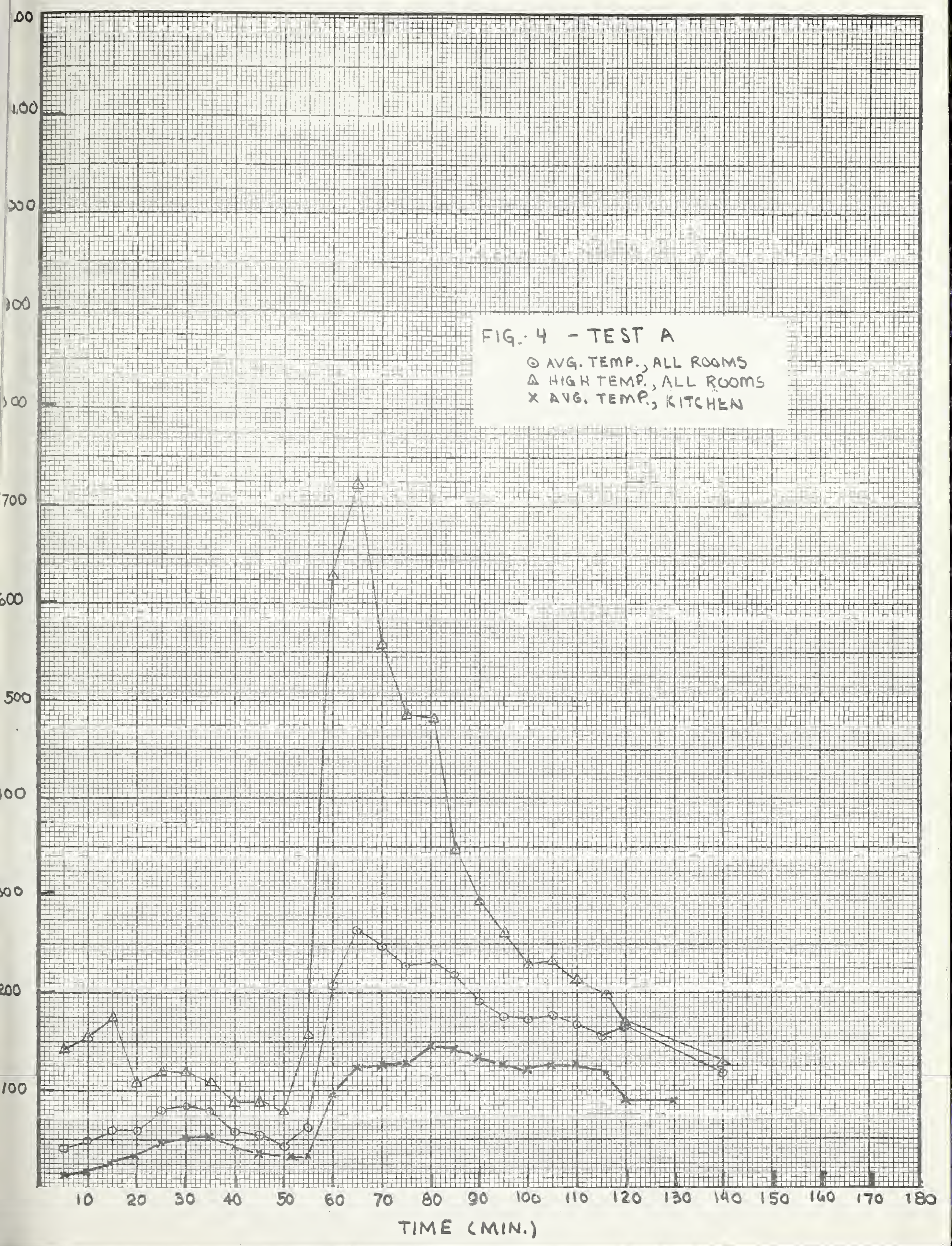


FIG. 4 - TEST A
⊙ AVG. TEMP., ALL ROOMS
△ HIGH TEMP., ALL ROOMS
× AVG. TEMP., KITCHEN
700
600
500
200
100
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
TIME (MIN.)

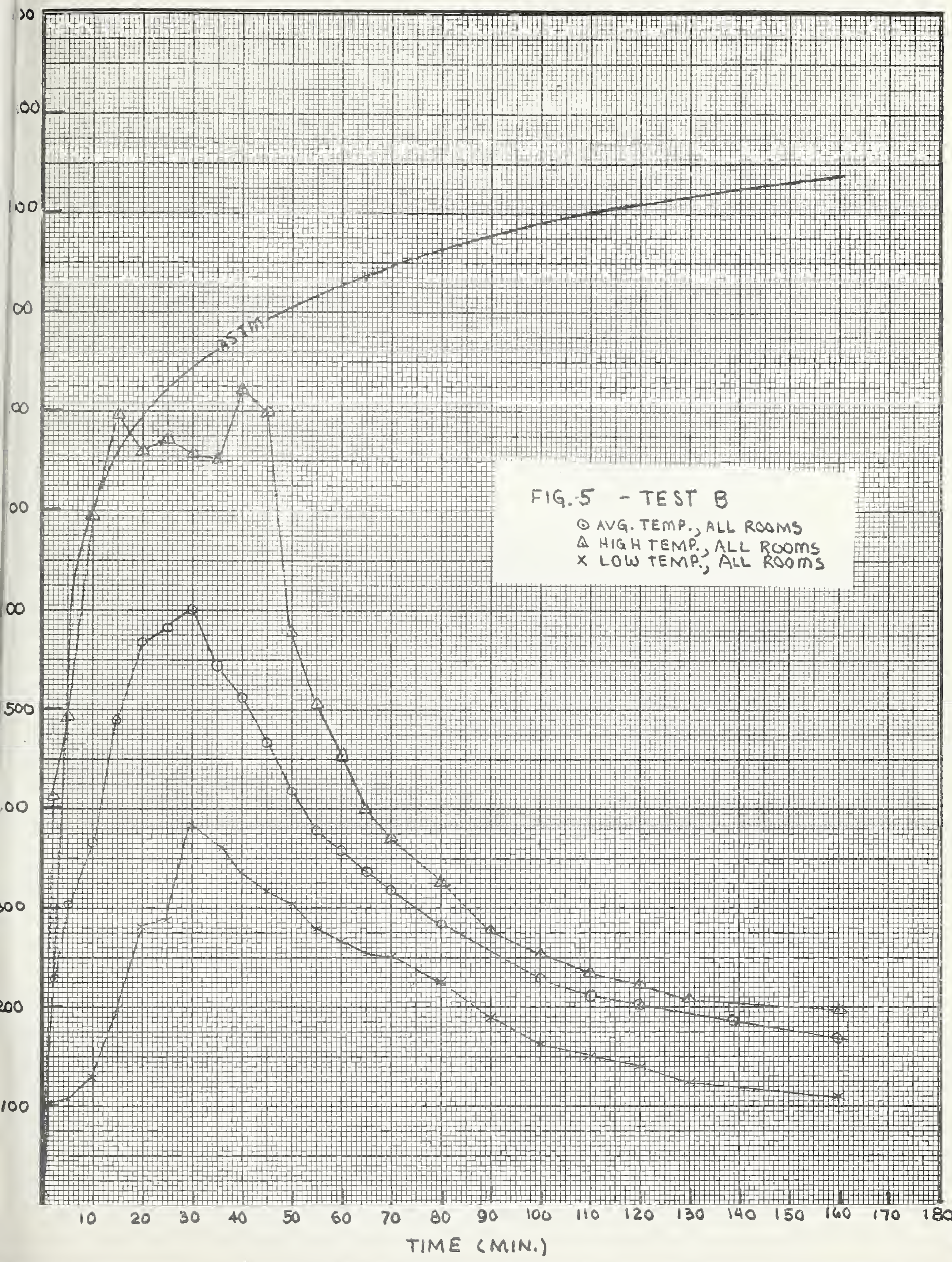


FIG. 5 - TEST B
⊙ AVG. TEMP., ALL ROOMS
△ HIGH TEMP., ALL ROOMS
× LOW TEMP., ALL ROOMS
ASTM
TIME (MIN.)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
500
200
100

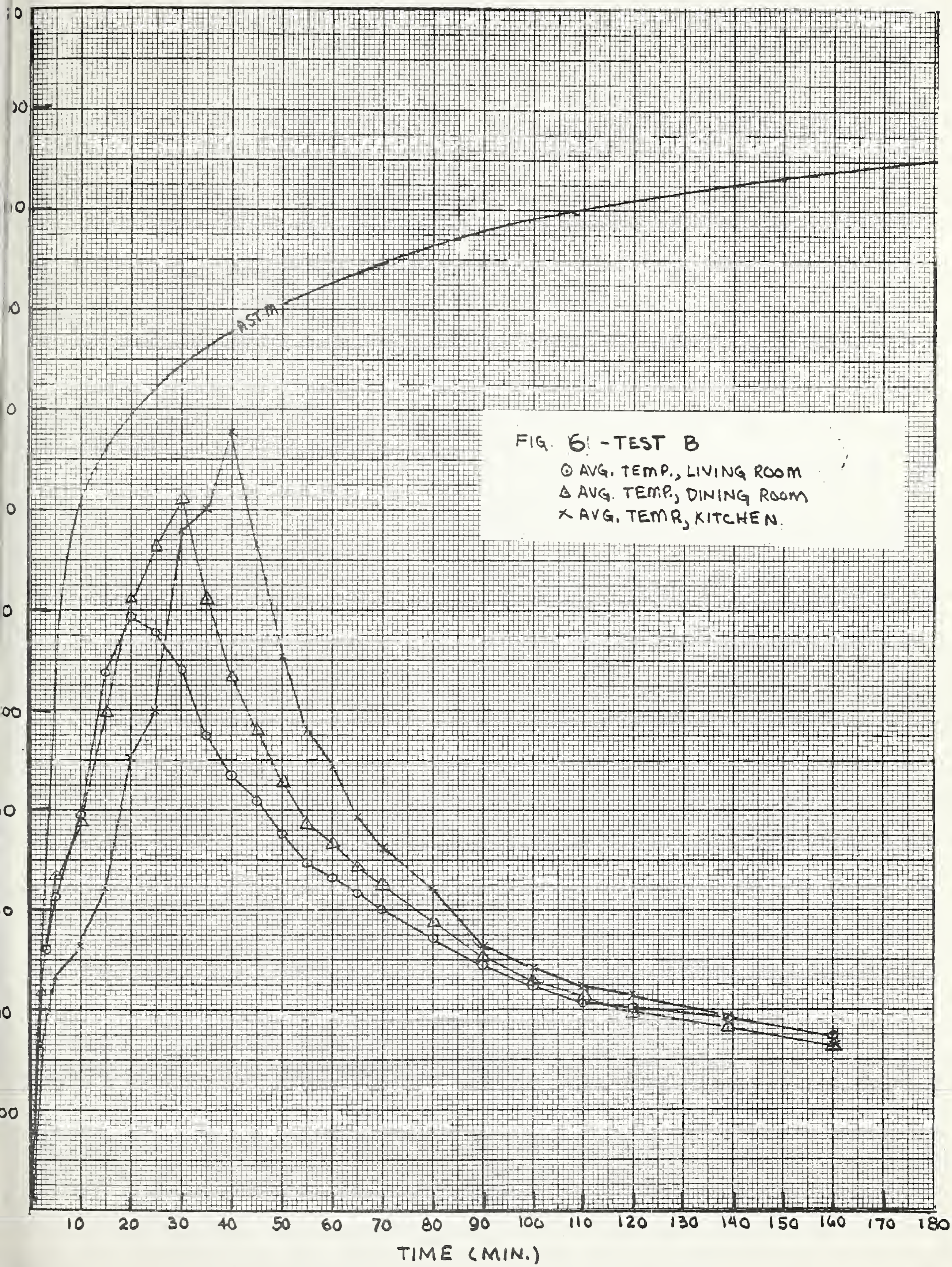


FIG. 6 - TEST B
⊙ AVG. TEMP., LIVING ROOM
△ AVG. TEMP., DINING ROOM
× AVG. TEMP., KITCHEN
ASTM
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
TIME (MIN.)

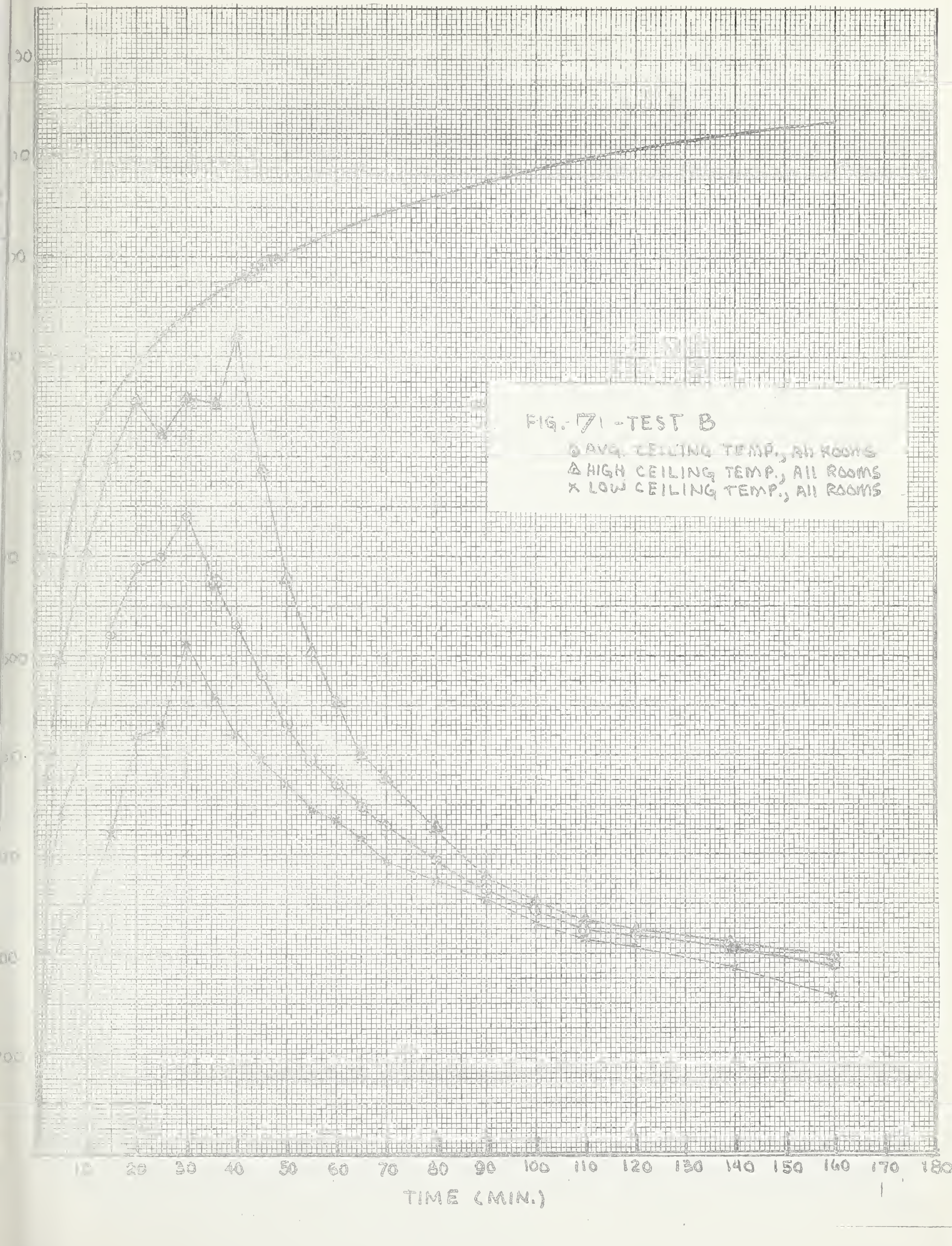


FIG. - 71 - TEST B
AVG. CEILING TEMP., All ROOMS
HIGH CEILING TEMP., All ROOMS
LOW CEILING TEMP., All ROOMS
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
TIME (MIN.)

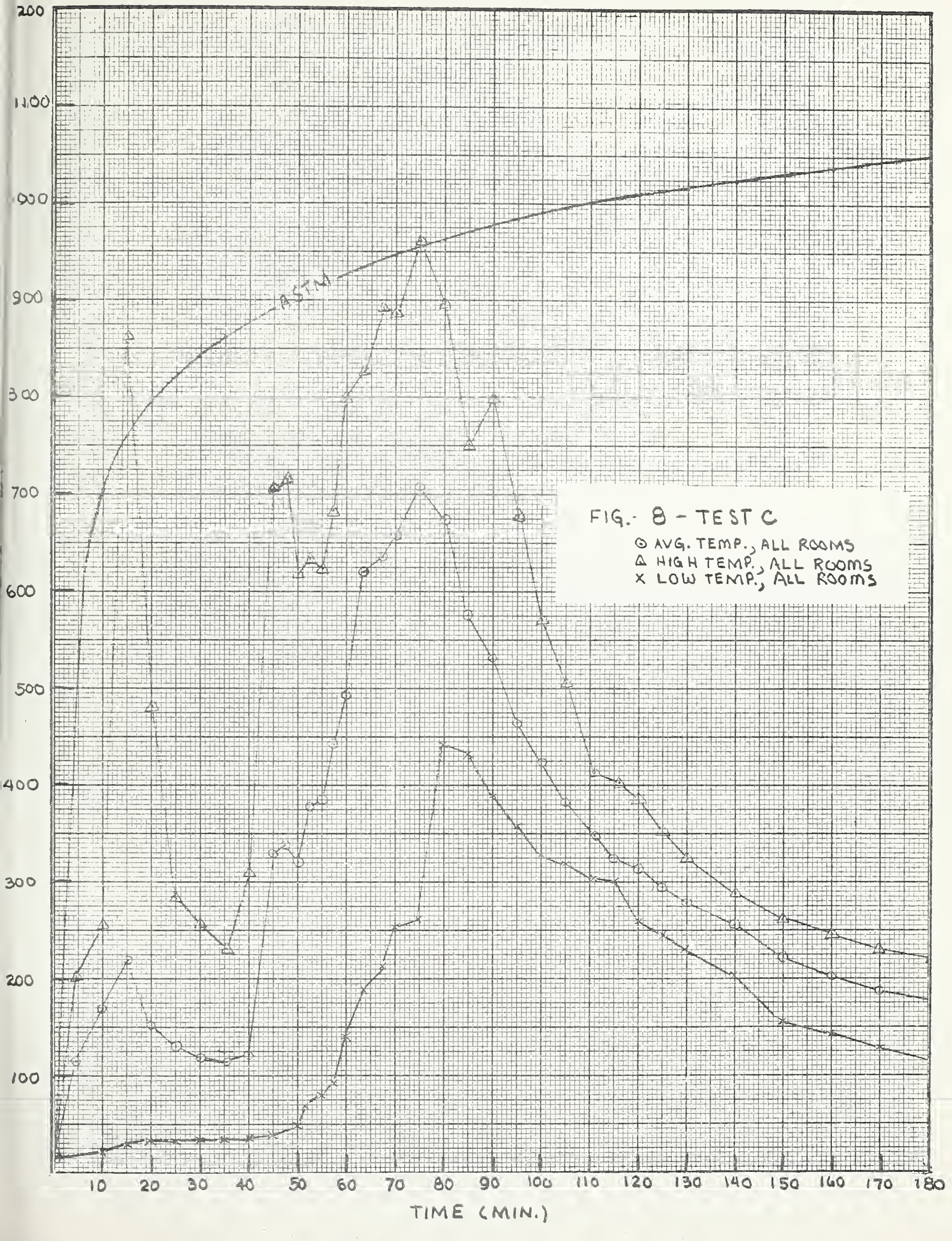


FIG.- 8 - TEST C
⊙ AVG. TEMP., ALL ROOMS
Δ HIGH TEMP., ALL ROOMS
× LOW TEMP., ALL ROOMS
ASTM
1200
1100
1000
900
800
700
600
500
400
300
200
100
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
TIME (MIN.)

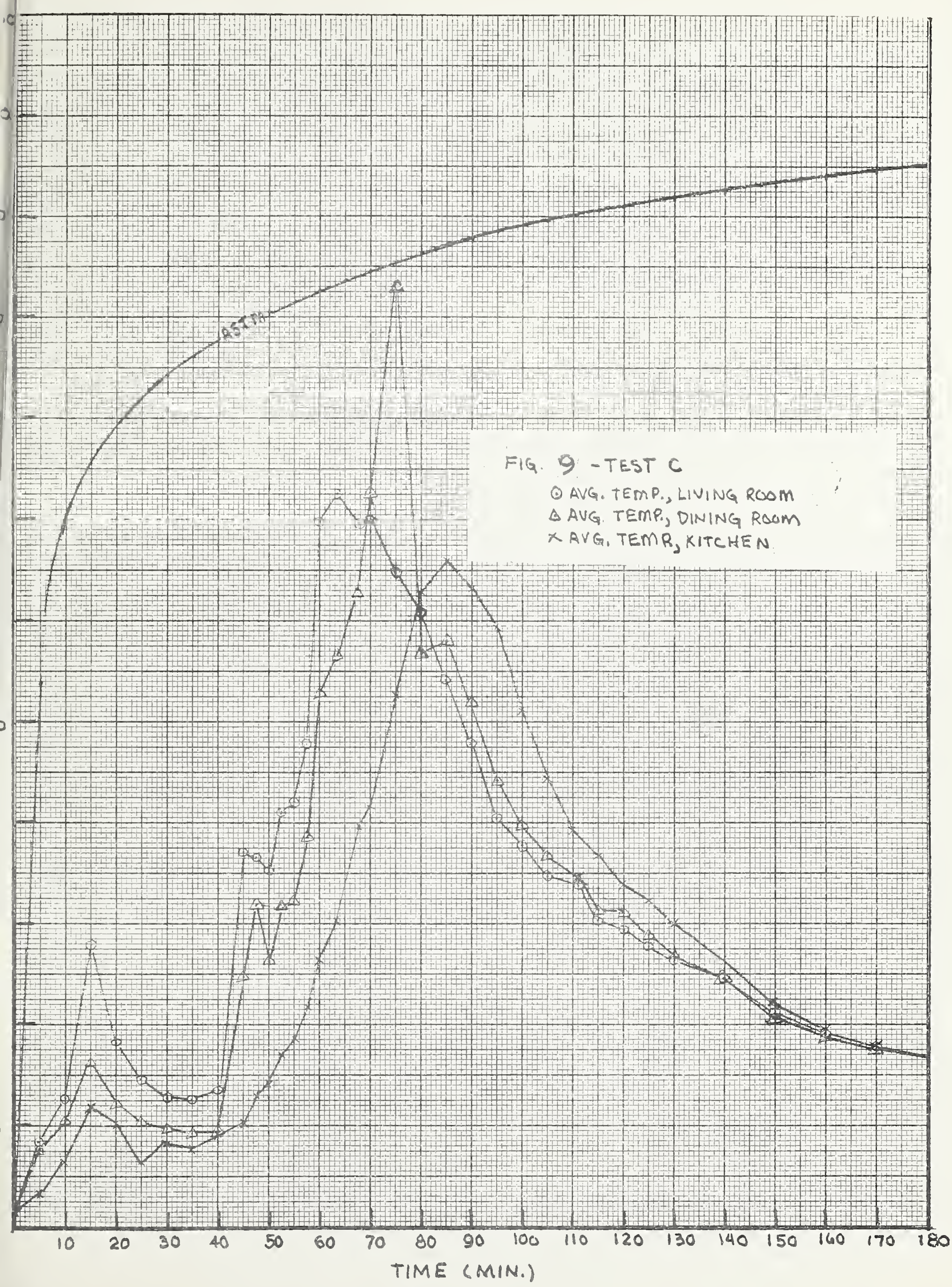


FIG. 9 -TEST C
⊙ AVG. TEMP., LIVING ROOM
△ AVG. TEMP., DINING ROOM
× AVG. TEMP., KITCHEN
ASTM
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
TIME (MIN.)

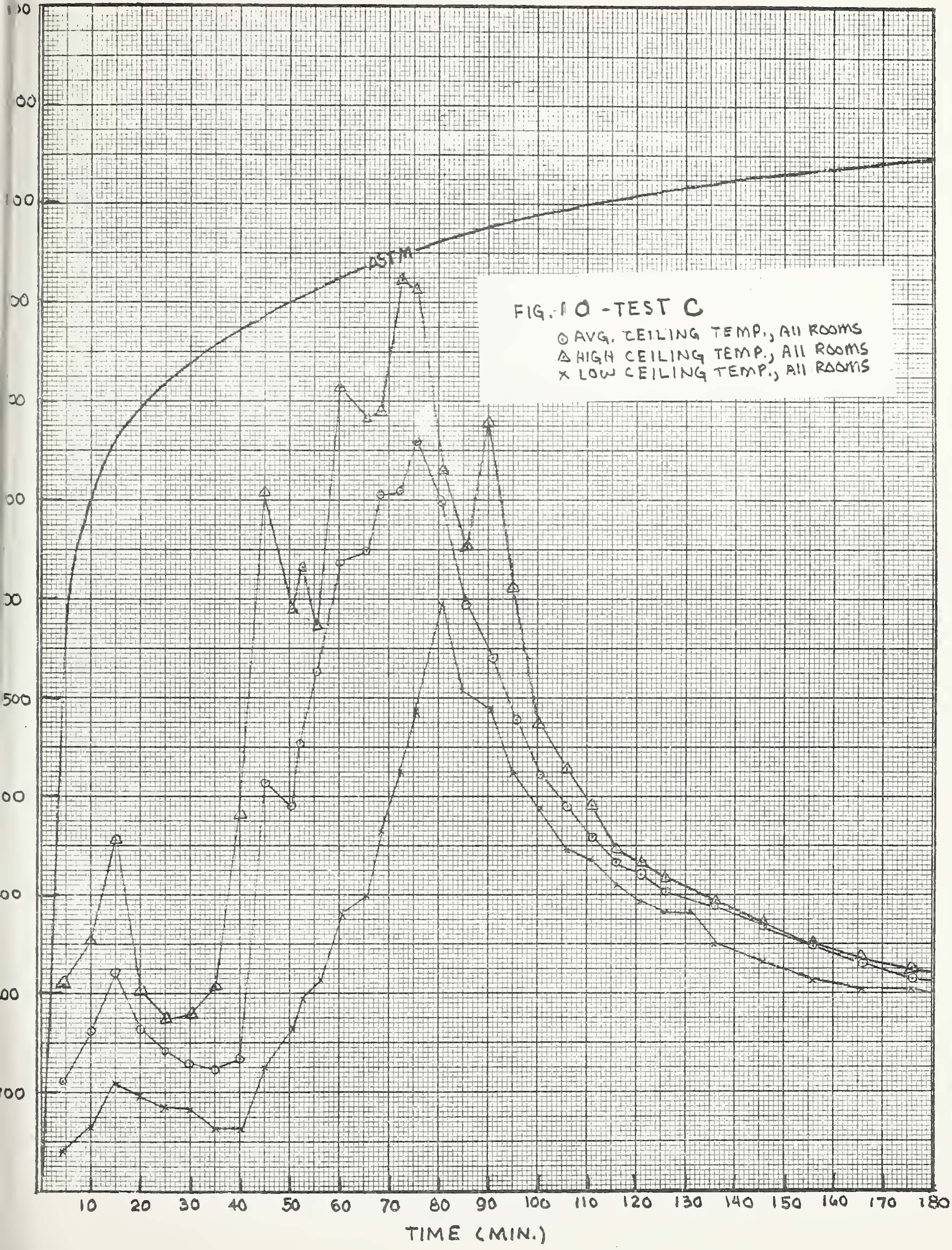


FIG. 10 - TEST C
⊙ AVG. CEILING TEMP., All Rooms
△ HIGH CEILING TEMP., All Rooms
× LOW CEILING TEMP., All Rooms
ASTM
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
TIME (MIN.)

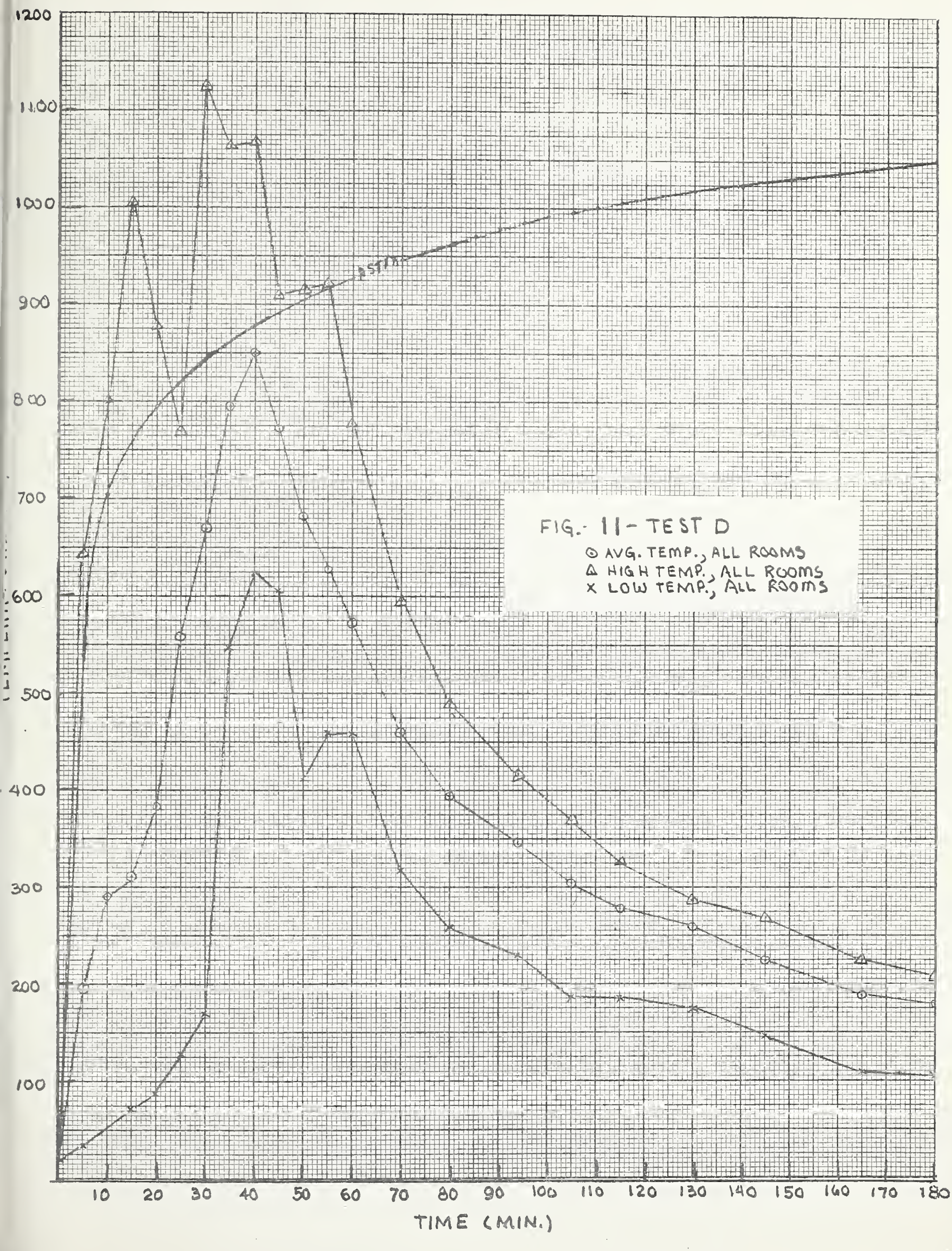


FIG.- 11 - TEST D
⊙ AVG. TEMP., ALL ROOMS
△ HIGH TEMP., ALL ROOMS
× LOW TEMP., ALL ROOMS
ASTM
1200
1100
1000
900
800
700
600
500
400
300
200
100
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
TIME (MIN.)

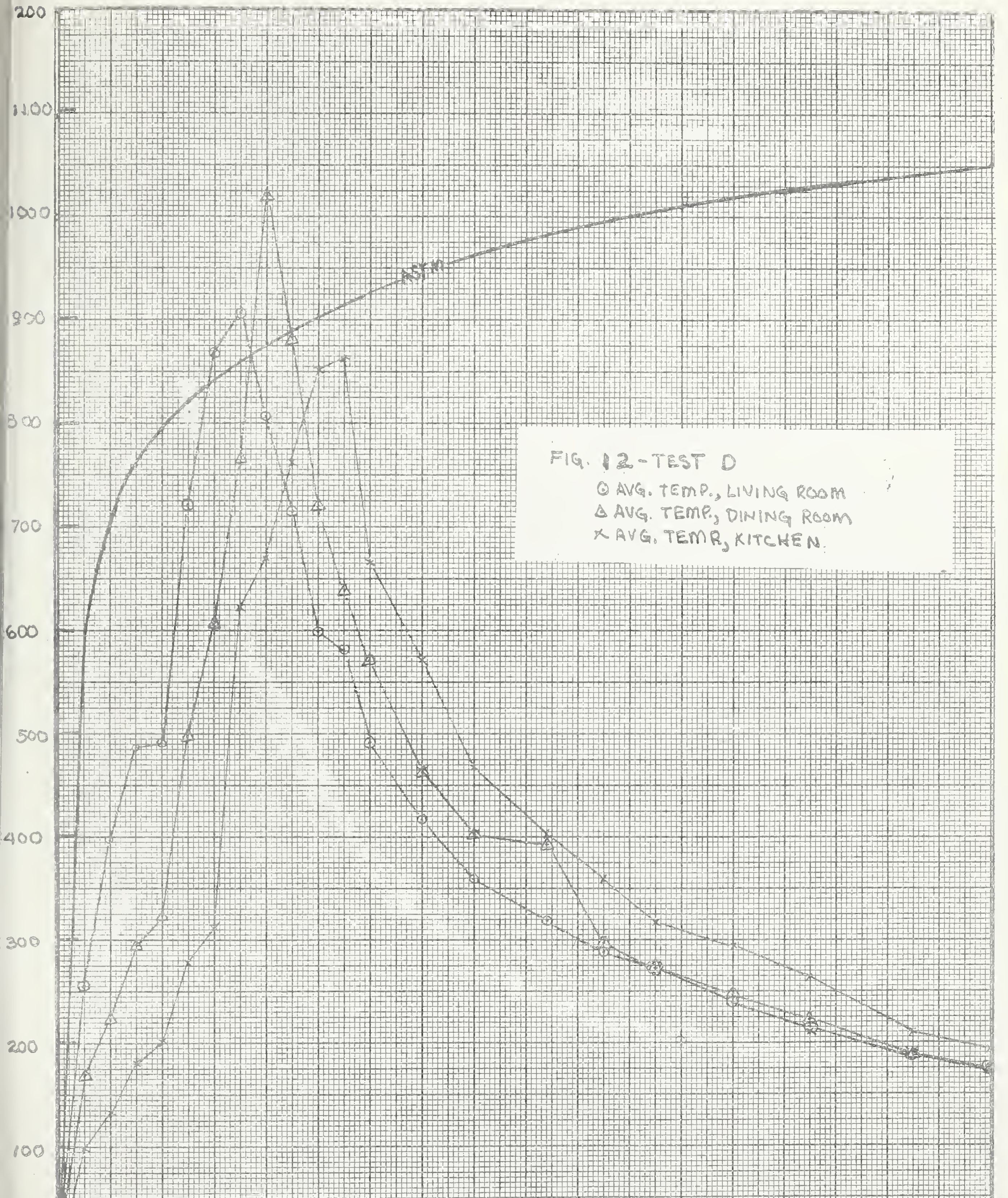


FIG. 12-TEST D
⊙ AVG. TEMP., LIVING ROOM
Δ AVG. TEMP., DINING ROOM
× AVG. TEMP., KITCHEN

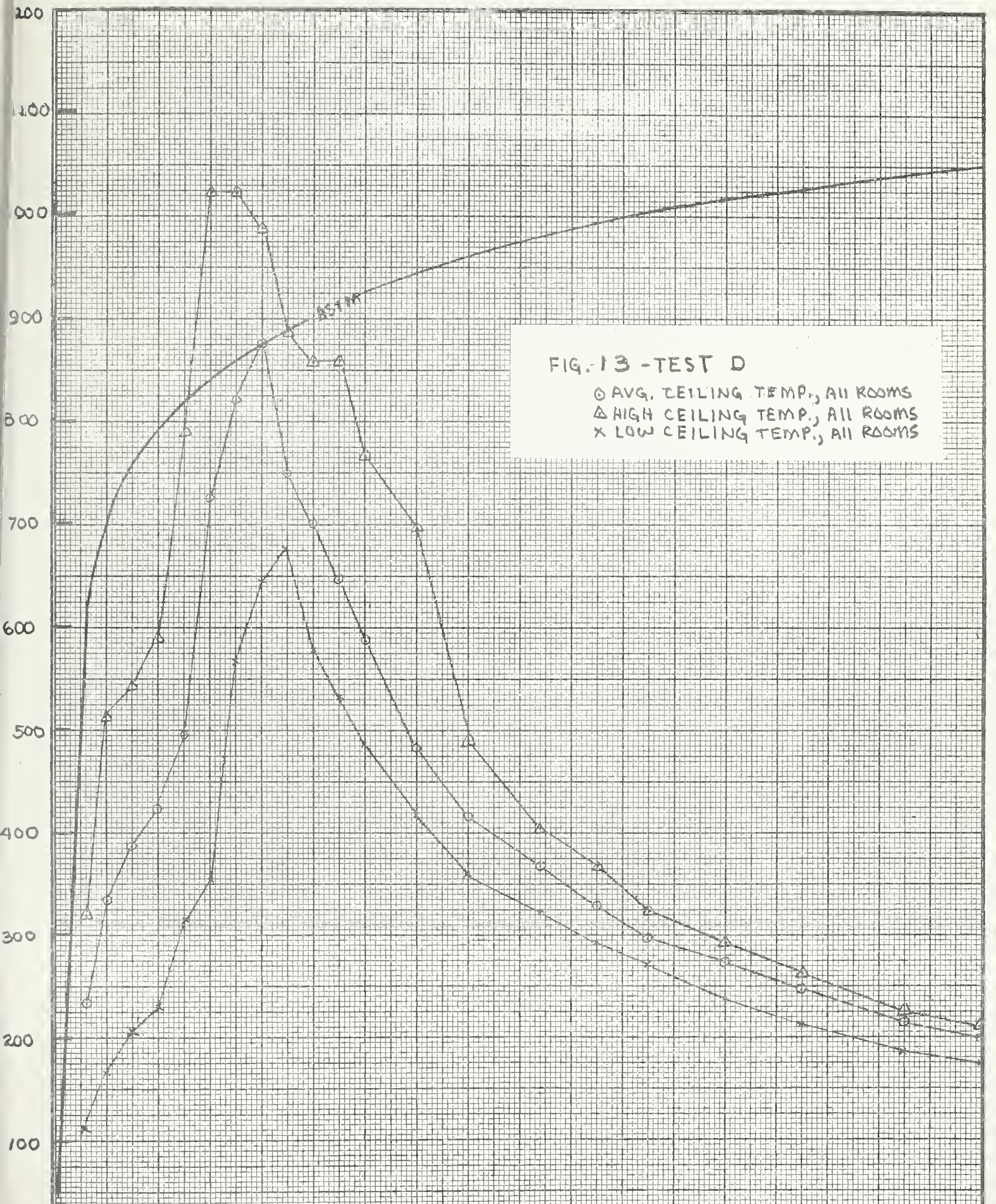


FIG.-13 -TEST D
⊙ AVG. CEILING TEMP., All ROOMS
△ HIGH CEILING TEMP., All ROOMS
× LOW CEILING TEMP., All ROOMS
ASTM
200
1100
1000
900
800
700
600
500
400
300
200
100
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
TIME (MIN.)

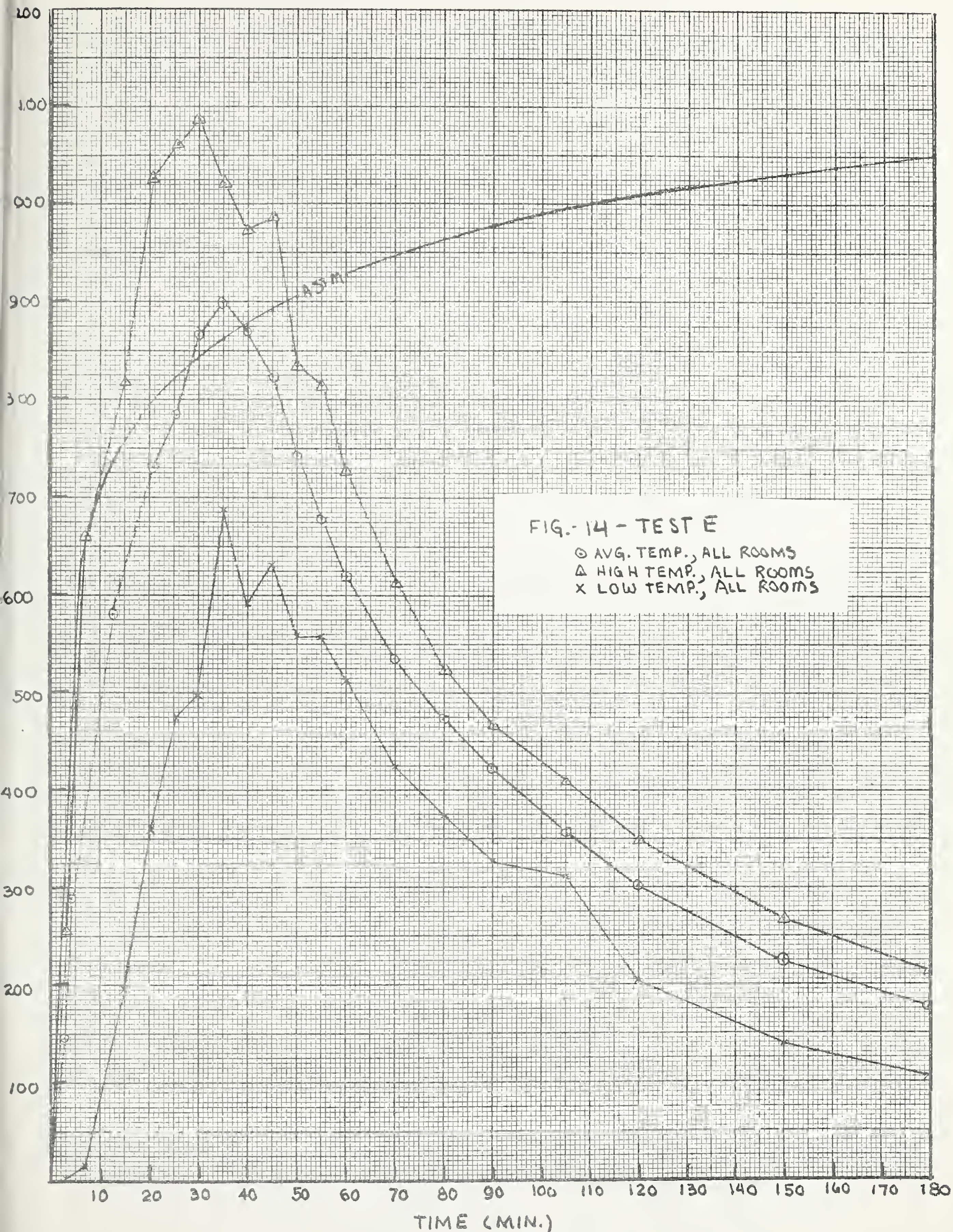


FIG.- 14 - TEST E
⊙ AVG. TEMP., ALL ROOMS
Δ HIGH TEMP., ALL ROOMS
x LOW TEMP., ALL ROOMS
A.S.T.M.
200
1.00
900
900
300
700
600
500
400
300
200
100
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
TIME (MIN.)

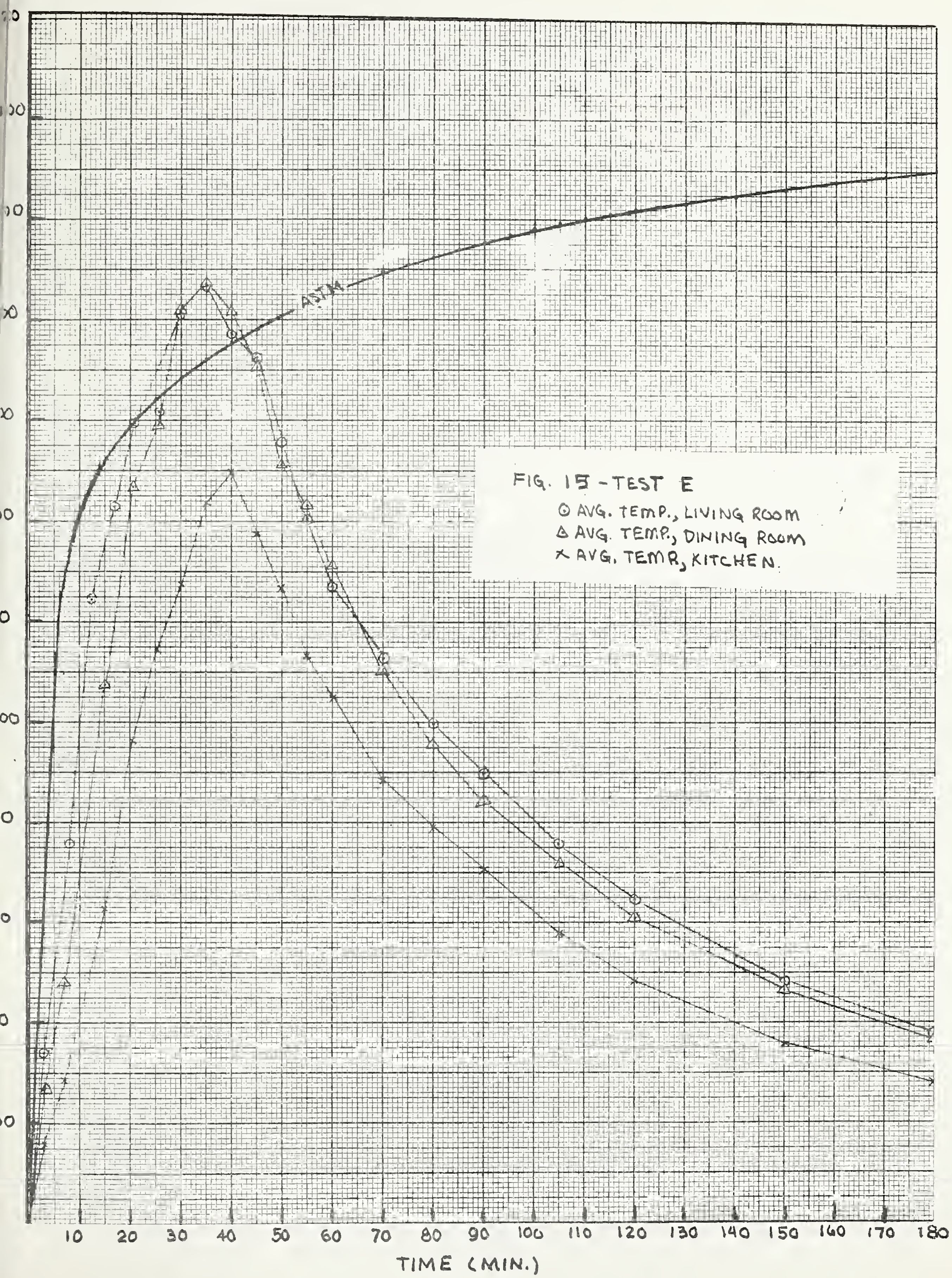


FIG. 15 - TEST E
⊙ AVG. TEMP., LIVING ROOM
△ AVG. TEMP., DINING ROOM
× AVG. TEMP., KITCHEN
ASTM
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
TIME (MIN.)

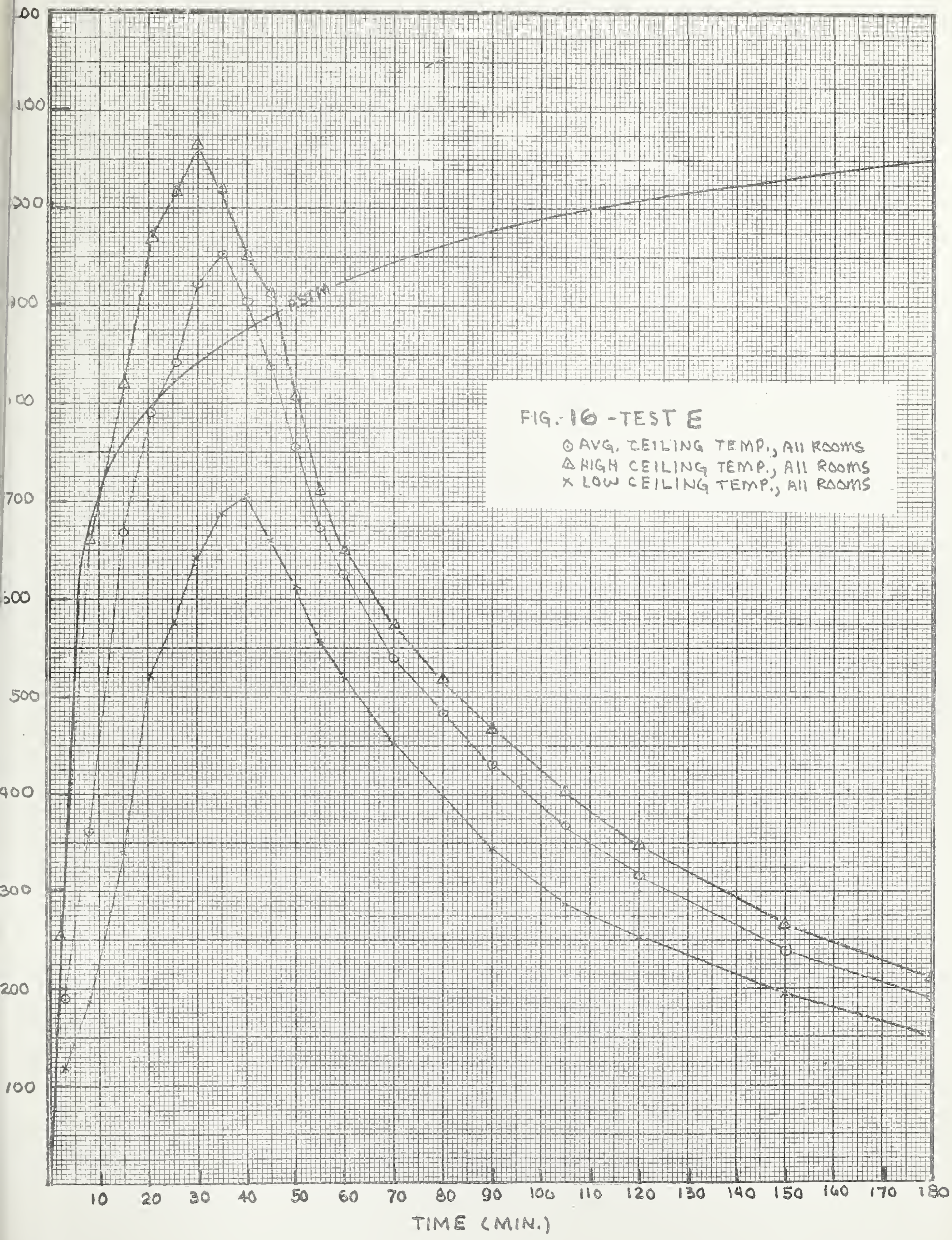


FIG. 16 - TEST E
⊙ AVG. CEILING TEMP., All ROOMS
△ HIGH CEILING TEMP., All ROOMS
× LOW CEILING TEMP., All ROOMS
ASTM
700
600
500
400
300
200
100
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
TIME (MIN.)

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